ORIGINAL RESEARCH

High lateral plantar pressure is related to an increased tibialis anterior/fibularis longus activity ratio in patients with recurrent lateral ankle sprain

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Introduction: Center of pressure (COP) is a sudden displacement at the time of a lateral ankle sprain (LAS). It has been suggested that the distribution of plantar pressure and the quantity of COP displacement are important for assessing the risk of LAS. Therefore, we evaluated the plantar pressure during a single-leg balance test with eyes closed (SLB-C) to identify the factors and characteristics of plantar pressure in people with repeated cases of LAS.

Methods: We recruited 22 collegiate athletes and divided them into an instability group (IG; n=11) and a control group (CG; n=11). We measured the distribution of plantar pressure and lower extremity muscle activity during a SLB-C along with static alignment and isometric ankle strength.

Results: The fibularis longus (FL) activity was significantly lower in the IG than in the CG. The lateral plantar pressure (LPP)/medial plantar pressure (MPP) ratio was also higher in the IG than in the CG. In addition, the LPP/MPP ratio was correlated with the tibialis anterior (TA)/FL ratio.

Conclusion: These results suggest that increased lateral plantar pressure is related to decreased FL activity and increased TA/FL ratio.

Keywords: chronic ankle instability, ankle sprain, postural stability, soccer, prevention

Introduction

Lateral ankle sprain (LAS) is a common injury in a collegiate athletic population, and according to a previous study by Gerber et al,[1] it accounts for ~21% of all injuries in the collegiate athletic population. In addition, at 7 years of follow-up, in 648 patients with LAS, >30% of patients still had some sequelae (e.g., pain, swelling, recurrent injury) and >70% of patients felt functionally impaired.[2] In addition, since repeated LAS is a risk factor for the early onset of posttraumatic ankle osteoarthritis, which impairs quality of life (QoL) in the future,[3] it is necessary to improve performance while screening clearly. From the abovementioned findings, as indicated in the 2016 consensus statement of the International Ankle Consortium,[4,5] LAS has a harmful effect on not only current sports activities but also future QoL. Moreover, it has been reported that an increasing lateral plantar pressure (LPP) and a considerable lateral displacement of the center of pressure (COP) are hallmarks of LAS injury.[6] Thus, the increasing LPP and the lateral displacement of COP are harmful characteristics that can cause LAS,[6] and it is clear that muscle activity has a large influence on plantar pressure distribution.[7] However, further research on the relationship between LPP and muscle activity related to hypofunction (especially, the fibularis longus [FL]) is needed.[8–10]

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It has been revealed that the FL contributes to ankle stability.[11] In particular, the FL contributes to frontal plane ankle stability during single-leg tasks[12] and is correlated with the amount of lateral–medial COP displacement.[13] From these studies, it can be considered that FL has an influence on the plantar pressure distribution. However, the influence of other muscles (tibialis anterior [TA] and gastrocnemius [GASTRO]), in terms of muscle activity interaction (e.g., agonist/antagonist activity ratio), on plantar pressure distribution is not clear. Since plantar pressure distribution is influenced by factors such as static alignment,[14] ankle strength,[15,16] and postural control[17,18] we have to measure many factors comprehensively to elucidate the relationship between muscle activity and plantar pressure distribution.

In the context of this background, this study aimed to investigate the relationship between increased LPP, characteristic of LAS, and lower extremity muscle activities, using a single-leg balance task with eyes closed (SLB-C) and assessing the ankle strength and static alignment. We believe that it is important to identify the factors that are related to increasing LPP and beneficial for designing training to prevent increasing LPP.

Methods
Subjects and study design
This study was conducted in a single-blind method as a retrospective cross-sectional study. A total of 68 collegiate athletes were screened for anthropometric data (height, weight, dominant leg, and history of LAS with medical examination) and Cumberland Ankle Instability Tool (CAIT) score using the CAIT questionnaire (Table 1).[19] In all, 11 athletes met the following inclusion criteria for the instability group (IG), based on a consensus statement and endorsement from the International Ankle Consortium:[20] 1) more than four counts of LAS with medical examination; 2) ongoing giving way experiences or feeling fear during sports activity; 3) CAIT score <24; 4) at least one LAS within the past year; and 5) no history of LAS within the past 3 months. We required the IG of more than

Table 1 Physical characteristics of participants

Variable	IG (n = 11)	CG (n = 11)
Age (years)	20.0±1.1	20.4±1.0
Height (cm)	175.9±3.5	176.6±5.2
Weight (kg)	68.6±5.3	72.2±5.1
Dominant legs measured	6/11	5/11
Cumberland ankle instability score	21.9±4.4	28.7±1.7**
Number of sprains (times)	5.1±1.0	0.0±0.0**

Notes: **$p<0.01$. All results are shown by mean ± standard deviation.
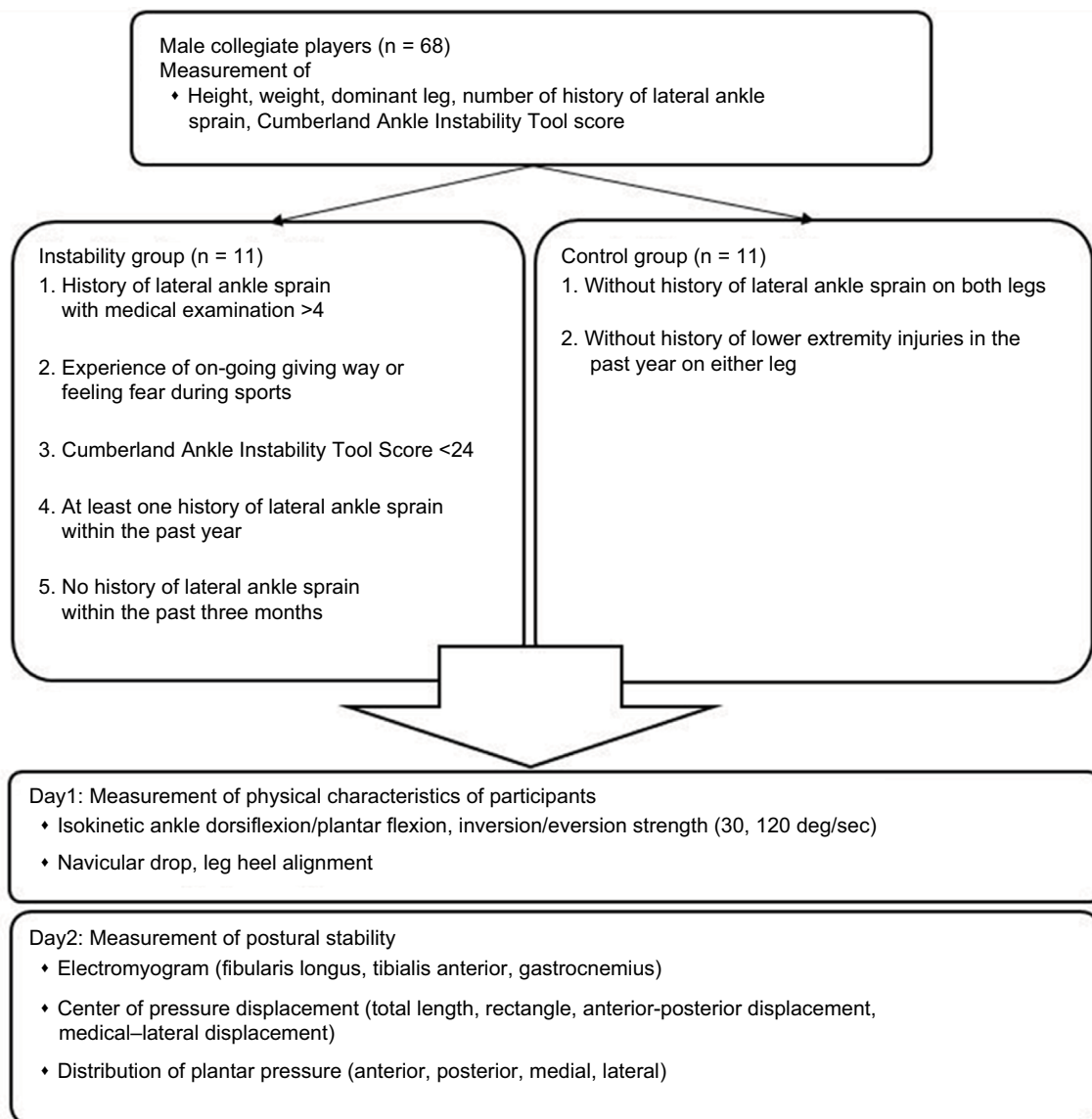**Abbreviations:** IG, instability group; CG, control group.

four counts of LAS with medical examination to ensure that the subjects had repeated LAS. A total of 11 participants were included in the control group (CG) based on the following criteria: 1) no history of LAS in either leg, and 2) no history of lower extremity injuries within 1 year. An LAS was defined as an ankle injury with an inversion mechanism requiring the player to miss at least one game or practice after a medical examination of the LAS by a physician. An ongoing giving way experience was defined as uncontrolled and unpredictable episodes of excessive inversion of the ankle at least two times in the 6 months prior to study enrollment.[20] Subjects were excluded if they had a history of fractures or surgery in the lower extremity or trunk. None of the subjects in either group reported a history of neurological or vestibular impairment. The target leg was selected at random in the CG. The dominant leg was determined by asking which leg the subject would use to kick a ball. The selection of subjects and the target leg was conducted by an author (S.M.). On the first day, we measured static alignment and ankle isokinetic strength. On another day, we measured COP displacement, distribution of plantar pressure, and muscle activity during the SLB-C task. The subjects were blinded during the measurement of variables.

SLB-C is the task of maintaining balance standing barefoot on one leg with eyes closed for 15 seconds.[21] We instructed subjects to put their hands on their waist and maintain a contralateral hip joint flexion at 90°. A trial was discarded if subjects did not keep their hands on their hips, if the balancing foot shifted, if the contralateral foot touched the ground, or if both legs were pushed together for balance.[22] After a practice trial, the SLB-C was repeated until two successful trials were completed. We set a rest period of 1 minute between SLB-C tasks.

We finished all the measurements within 2 weeks (Figure 1). This study was carried out in accordance with the principles outlined in the Declaration of Helsinki of the World Medical Association and was approved by the ethics committee of Medical and Health Research Involving Human Subjects of Waseda University, and all the participants signed an informed consent form.

Measurement of isokinetic strength
We measured ankle isokinetic concentric dorsiflexion, plantar flexion, and inversion and eversion strength using a Biodex System III Dynamometer (Biodex Medical Systems; Shirley, NY, USA). These tests were conducted at speeds of 30°/second and 120°/second. The knee was positioned at 0°, and the ankle joint was positioned such that the subtalar joint became dorsi-/plantarflexion 0° during dorsi-/plantarflexion measurement.

Male collegiate players (n = 68)
Measurement of
• Height, weight, dominant leg, number of history of lateral ankle sprain, Cumberland Ankle Instability Tool score

Instability group (n = 11)
1. History of lateral ankle sprain with medical examination >4

2. Experience of on-going giving way or feeling fear during sports

3. Cumberland Ankle Instability Tool Score <24

4. At least one history of lateral ankle sprain within the past year

5. No history of lateral ankle sprain within the past three months

Control group (n = 11)
1. Without history of lateral ankle sprain on both legs

2. Without history of lower extremity injuries in the past year on either leg

Day1: Measurement of physical characteristics of participants
• Isokinetic ankle dorsiflexion/plantar flexion, inversion/eversion strength (30, 120 deg/sec)
• Navicular drop, leg heel alignment

Day2: Measurement of postural stability
• Electromyogram (fibularis longus, tibialis anterior, gastrocnemius)
• Center of pressure displacement (total length, rectangle, anterior-posterior displacement, medical–lateral displacement)
• Distribution of plantar pressure (anterior, posterior, medial, lateral)

Figure 1 General procedure.
Note: 'On-going giving way' is defined as uncontrolled and unpredictable episodes of excessive inversion of the ankle at least two times in the 6 months prior to study enrollment.

The trunk and femur were fixed to the seat and the ankle to the footplate with straps. Both arms were crossed in front of the chest during measurement. The rotational axis of the dynamometer was positioned on the lateral malleolus.[23] For the inversion test, the knee was flexed 60° and the ankle joint was positioned such that the subtalar joint became dorsi-/plantarflexion 0° during inversion/eversion measurement. The range of motion stop angle was set at full range of motion. Before testing, a warm-up session was performed to allow familiarization with the testing protocol. The warm-up session consisted of a submaximal five trials (~50%)[24] before each test. Five maximal repetitions were recorded for each of the test conditions. Consistent verbal encouragement for each

maximal effort was given to the subject throughout the test. A 3-minute rest period was provided between efforts, and subjects were instructed that their best effort was required. The average torque value (normalized to body weight) for each condition was used in the data analysis to detect group differences.

Navicular drop

Navicular drop (ND) was calculated using an iron ruler in a seated position. Subjects sat on a chair and placed their foot on a scale (HA552; Tanita, Itabashi Ward, Tokyo, Japan). We regulated the height of the chair so that their thigh was parallel to the ground, and their ankle position was dorsi-/plantarflexion 0° to load for 10% of weight. We measured the

distance between the navicular tuberosity and the ground in the sitting and standing positions and defined the difference as the ND. The measurement was performed two times, and the average value was used in the data analysis.

Leg heel alignment

We marked three points on the subject's leg and defined the angle created by segments A–B and B–C as leg heel alignment (LHA; Figure 2).[25] We marked point A in the lower one-third, central part of the leg, point B on the calcaneal tuberosity, and point C on the heel so that the segment B–C divided the heel in half. We took a picture of the lower limb from behind the subject using a digital camera (EXILIM EX-FX1; Casio, Shibuya Ward, Tokyo, Japan). LHA was determined from the picture using the 2D image analysis software (Dartfish; gsport, Bunkyo Ward, Tokyo, Japan).

Distribution of plantar pressure and COP displacement

We measured anterior plantar pressure (APP), posterior plantar pressure (PPP), medial plantar pressure (MPP), LPP, total length of COP anterior–posterior (A–P) displacement, total length of COP medial–lateral (M–L) displacement, total length of COP (LNG), and rectangle area (RA) during the balance task. We calculated the PPP/APP ratio and LPP/MPP ratio from the data. Plantar pressure distribution and COP displacement data were measured at 100 Hz using the plantar pressure sensor (F-scan II; Nitta, Osaka, Japan). Plantar pressure distribution was recorded per unit area (kg/cm^2). We recorded plantar pressure distribution during

a balance task for 15 seconds, and the results were normalized to body weight.[21] We defined line A as the connection between the second distal phalanx and the calcaneus and line B as the line crossing line A at a right angle. We determined the portion one-third anterior to line B as the APP area and the portion one-third posterior to line B as the PPP area. In addition, we determined the portion one-third inside of line A as the MPP area and one-third outside of line A as the LPP area (Figure 3). Since this definition of plantar pressure area was used in the original method, we calculated an intraclass correlation coefficient (ICC) value before data collection (n = 8). All areas had a high reliability (ICC [1, 2]: APP = 0.985, PPP =0.878, LPP =0.997, MPP =0.992, LPP/MPP ratio =0.973, PPP/APP ratio =0.778; Table 2). Thus, the average value of plantar pressure and COP displacement in two SLB-C tasks was used for analysis.

Electromyography

We measured the FL, TA, and GASTRO lateral muscle activity by means of surface electromyography (TeleMyo 2400T; Noraxon, Scottsdale, AZ, USA) at 1500 Hz during SLB-C. The preparation consisted of shaving the skin over the area of electrode placement, followed by cleaning the skin with alcohol swabs. Disposable Ag/AgCl circular electrodes were placed over each muscle. Electrode placement was consistent with a previous study.[26] Before recording the SLB-C trial, 5-second maximum voluntary isometric contractions (MVICs) against manual resistance were recorded to normalize the electromyography (EMG) amplitude during the SLB-C trials. We calculated root mean square (RMS) value
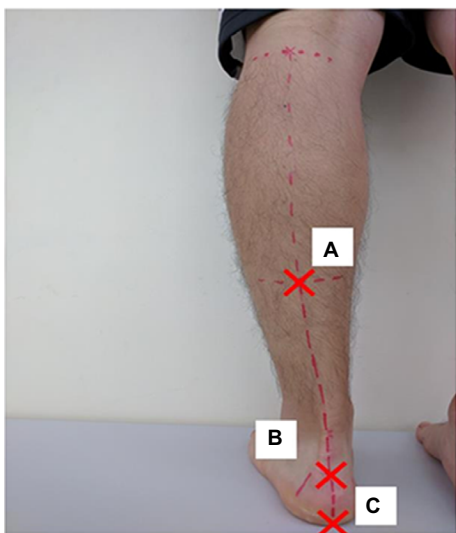

Figure 2 The definition of leg heel alignment
Notes: Point A is on a lower one-third central part of the tibia. Point B is on a calcaneal tuberosity. Point C is on a heel so that line B–C divided a heel in a half.
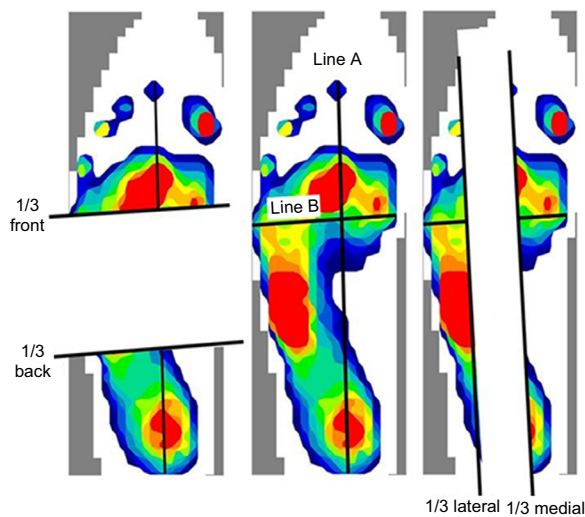

Figure 3 Distribution of plantar pressure.
Notes: Line A connects the second distal phalanx and calcaneus. Line B crosses line A at a right angle.

Table 2 Intra-class correlation coefficient value of plantar pressure

	APP	PPP	PPP/APP	MPP	LPP	LPP/MPP
ICC (1, 2)	0.985	0.878	0.774	0.992	0.997	0.973

Abbreviations: APP, anterior plantar pressure; PPP, posterior plantar pressure; MPP, medial plantar pressure; LPP, lateral plantar pressure; ICC, intraclass correlation coefficient.

from an interval of the middle 3 seconds and assumed the value as 100% RMS. We normalized the EMG signals during SLB-C to 100% RMS and the average value of RMS during 15 seconds of SLB-C. All muscle activities during SLB-C and MVICs, after full-wave rectification, were filtered by a band-pass filter with a cutoff frequency of 5–500 Hz using the TRAIS System (DKH, Itabashi Ward, Tokyo, Japan).

Statistical analysis

First, we performed the Kolmogorov–Smirnov test as the test of normality. We performed independent t-tests for the variables that had a normal distribution. We performed the Mann–Whitney U test for the variables that were not normally distributed. In addition, Spearman's rank-order correlation analysis was used to evaluate the relationships among static alignment (LHA and ND), EMG, isokinetic strength, and all of the plantar pressure measures. The level of significance was set a priori at $p < 0.05$ using the statistical software program (Excel analysis; SSRI, Shinjuku Ward, Tokyo, Japan) for all analyses. We calculated the effect size, using Cohen's d coefficient, and 95% confidence intervals (CIs) around Cohen's d (Figure 4).[27]

Results

Kolmogorov–Smirnov testing revealed a non-normal distribution for FL activity, dosiflexion/plantarflexion strength ratio (30°/second), inversion strength (30/second), and eversion strength (30°/second).

Distribution of plantar pressure, muscle activity, and COP displacement

MPP during SLB-C was lower in the IG compared to the CG ($p<0.05$, Cohen's $d = -1.12$ [95% CI, -1.10 to 3.38], $1 - \beta = 0.70$), and LPP/MPP ratio was higher in the IG compared to the CG ($p<0.05$, Cohen's $d = 1.00$ [95% CI, -1.19 to 3.29], $1 - \beta = 0.61$; Table 3). FL activity was significantly lower in the IG than in the CG ($p<0.05$, Cohen's $d = 0.99$ [95% CI, -1.20 to 3.27], $1 - \beta = 0.58$), and TA/FL ratio was significantly higher in the IG than in the CG ($p<0.05$, Cohen's $d = 1.44$ [95% CI, -0.77 to 3.75], $1 - \beta = 0.89$; Table 3 and 5). In addition, FL activity was correlated with LPP and LPP/MPP ratio. The TA/FL ratio was correlated with MPP and

$$d = \frac{m_2 - m_1}{S_{\text{pooled}}}$$

$$S_{\text{pooled}} = \sqrt{\frac{(n_2 - 1)S_2^2 + (n_1 - 1)S_1^2}{n_1 + n_2 - 2}}$$

$$Se = \sqrt{\left(\frac{n_1 + n_2 - 1}{n_1 + n_2 - 3}\right)\left[\left(\frac{4}{n_2 + n_2}\right)\left(1 + \frac{d^2}{8}\right)\right]}$$

95% CI = $ES - 1.96se$ to $ES + 1.96se$,

Figure 4 Calculation of Cohen's d and 95% CIs around Cohen's d.
Notes: "m_1" and "m_2" are the average of two groups. "n_1" and "n_2" are the sample size of two groups. "S_1^2" and "S_2^2" are the variance of two groups.
Abbreviations: CI, confidence interval; ES, effect size (Cohen's d).

Table 3 Variables measured during the balance task

Variable	IG (n=11)	CG (n=11)
COP displacement		
A–P displacement (mm)	355.4±159.7	397.7±219.6
M–L displacement (mm)	154.4±45.8	139.8±50.4
Total length (mm)	581.5±224.3	576.1±374.4
RA (mm²)	129.2±59.8	134.2±110.5
Distribution of plantar pressure		
APP (kg/cm²)	3.54±1.45	3.16±1.51
PPP (kg/cm²)	2.25±0.89	2.60±1.85
MPP (kg/cm²)	1.98±1.07	4.58±3.21*
LPP (kg/cm²)	3.47±1.64	3.86±2.42
PPP/APP ratio (%)	93.5±45.0	79.8±40.9
LPP/MPP ratio (%)	203.1±91.7	121.6±69.4*
Muscle activity		
FL (%RMS)	65.5±40.9	98.9±24.9*
TA (%RMS)	52.2±11.5	41.6±24.1
GASTRO (%RMS)	221.7±149.2	166.0±96.7
TA/FL ratio (%)	91.9±31.1	47.1±31.9*
TA/GASTRO ratio (%)	466.2±338.7	585.8±492

Notes: *$p<0.05$. All results are shown by mean ± standard deviation.
Abbreviations: IG, instability group; CG, control group; COP, center of pressure; A–P, anterior–posterior; M–L, medial–lateral; RA, rectangle area; APP, anterior plantar pressure; PPP, posterior plantar pressure; MPP, medial plantar pressure; LPP, lateral plantar pressure; FL, fibularis longus; RMS, root mean square; TA, tibialis anterior; GASTRO, gastrocnemius.

the LPP/MPP ratio (Table 4). No significant difference was found in APP, PPP, LPP, or PPP/APP; COP A–P displacement; COP M–L displacement; LNG; or RA (Tables 3 and 5 and Figure 6).

Measurement of ankle isokinetic strength and static alignment

There were no significant differences in concentric isokinetic ankle strength, LHA, and ND between IG and CG (Table 5).

Discussion

In this study, we investigated the characteristics of the distribution of plantar pressure and muscle activity and the relationships between these measures. Our results showed

Table 4 Correlation coefficient value between muscle activities and plantar pressure

Variable	MPP	LPP	LPP/MPP
FL	NS	r = −0.536*	r = −0.443*
TA	NS	NS	NS
GASTRO	NS	NS	NS
TA/FL ratio (%)	r = −0.471*	NS	r =0.447*
TA/GASTRO ratio (%)	NS	NS	NS

Note: *p<0.05.
Abbreviations: MPP, medial plantar pressure; LPP, lateral plantar pressure; FL, fibularis longus; NS, not significant; TA, tibialis anterior; GASTRO, gastrocnemius.

Table 5 Characteristics of strength and foot posture

Variable	IG (n=11)	CG (n=11)
Strength		
30°/second dorsiflexion (%)	114.6±25.5	125.9±41.9
30°/second plantarflexion (%)	64.1±7.5	70.7±7.0
30°/second inversion (%)	26.1±6.1	30.4±11.8
30°/second eversion (%)	32.4±4.9	30.3±8.7
30°/second dorsiflexion/ plantarflexion (%)	182.0±54.3	174.6±45.4
30°/second inversion/eversion (%)	130.2±33.0	107.3±28.5
120°/second dorsiflexion (%)	32.6±7.5	36.1±7.6
120°/second plantarflexion (%)	44.4±22.9	49.3±28.8
120°/second inversion (%)	14.6±5.6	15.2±5.9
120°/second eversion (%)	17.6±2.9	17.2±5.4
120°/second dorsiflexion plantarflexion (%)	131.7±54.2	128.5±57.2
120°/second inversion eversion (%)	130.8±44.6	119.1±30.9
Static alignment		
Leg heel angle (°)	4.0±2.5	4.1±2.6
ND (cm)	1.0±0.2	0.8±0.3

Notes: All results are shown by mean ± standard deviation.
Abbreviations: IG, instability group; CG, control group; ND, navicular drop.

that in the IG, there was more loading toward the outside of the foot during SLB-C than in the CG and the FL was lower and TA/FL ratio was higher. In addition, the MPP was correlated with the TA/FL ratio. The LPP was correlated with FL activity. The LPP/MPP ratio was correlated with the FL activity and the TA/FL ratio. Our study showed that the LPP/MPP ratio was increased with decreasing MPP in chronic ankle instability (CAI) patients, and this was related to diminished FL activity and increasing TA/FL ratio. To the best of our knowledge, this result is shown first by our study. The increasing LPP/MPP ratio with decreasing MPP indicates increasing loading in the lateral direction, which is considered as a harmful position that could lead to re-sprain.[6]

A previous study has shown that FL activity contributes to frontal plane ankle stability,[13] and our study suggests that FL activity prevents loading toward the outside of the foot. In addition, a previous study showed that FL activity prevents the ankle from inverting excessively[12] and increases with added perturbation, which increases LPP.[28] From these

previous studies, it can be considered that FL has the function of preventing increasing LPP by exhibiting eversion torque, and in the IG in our study, this preventive function may have been diminished. In addition, there were no significant differences in static alignment,[14] ankle strength,[15,16] and postural control,[17,18] which have an influence on plantar pressure distribution. So it was suggested that the increasing LPP/ MPP is related to decreasing FL function, which prevents LPP from increasing, and the relative enhancement of the inversion function of TA.

Decreasing FL activity was consistent with the findings of a previous study.[29] Rodriguez-Fernandez et al[30] suggested decreased excitability of the common peroneal nerve in people with a history of LAS. In addition, Kim et al[31] showed a decrease in the Hoffmann's reflex (H-reflex) in an injured group compared to a CG. It was suggested that there are some changes not only in peripheral function but also in the central nervous system. Futatsubashi et al[32] showed increasing gains of the suppressive cutaneous reflex (CR) and implied that impairment of the CR pathway, including the spinal and supraspinal pathways, occurs in CAI patients.[32,33] In addition, the CR is important for motor control of the closed kinetic chain (CKC) and is affected by the cutaneous mechanoreceptor.[34] It has been shown that the sensitivity of the calcaneal cutaneous mechanoreceptor is diminished in CAI patients.[35] Furthermore, Pietrosimone and Gribble [36] showed a relationship between FL motor threshold of corticomotor pathway as assessed using transcranial magnetic stimulation (TMS) and subjective feelings of instability. From these studies, it is clear that the reflex pathway, including the spinal and supraspinal levels, is impaired in CAI patients. Thus, it is possible that this diminished FL activity is related to the impaired reflex pathway and sensorimotor deficits. On the other hand, Tokuno et al[37] showed that the COP displacement has an effect on the H-reflex and stretch reflex excitability. Additionally, the amplitude of the H-reflex following conditioning cutaneous stimulation depends on the stimulation area of the plantar cutaneous.[38] From these previous studies, it can be concluded that it is possible that the altered FL activity was influenced by the plantar pressure distribution itself. Delahunt et al[39] have suggested that the increasing activity of the FL occurs by feed-forward motor control to increase ankle stability after landing. Thus, it is possible that the feed-forward mechanism of our subjects was altered in our study. Consequently, it is considered that the decreasing FL activity might be related to these altered spinal-level or supraspinal-level motor control mechanisms.

Our results showed that MPP is correlated with the TA/ FL ratio and not only FL activity, and this result suggests that
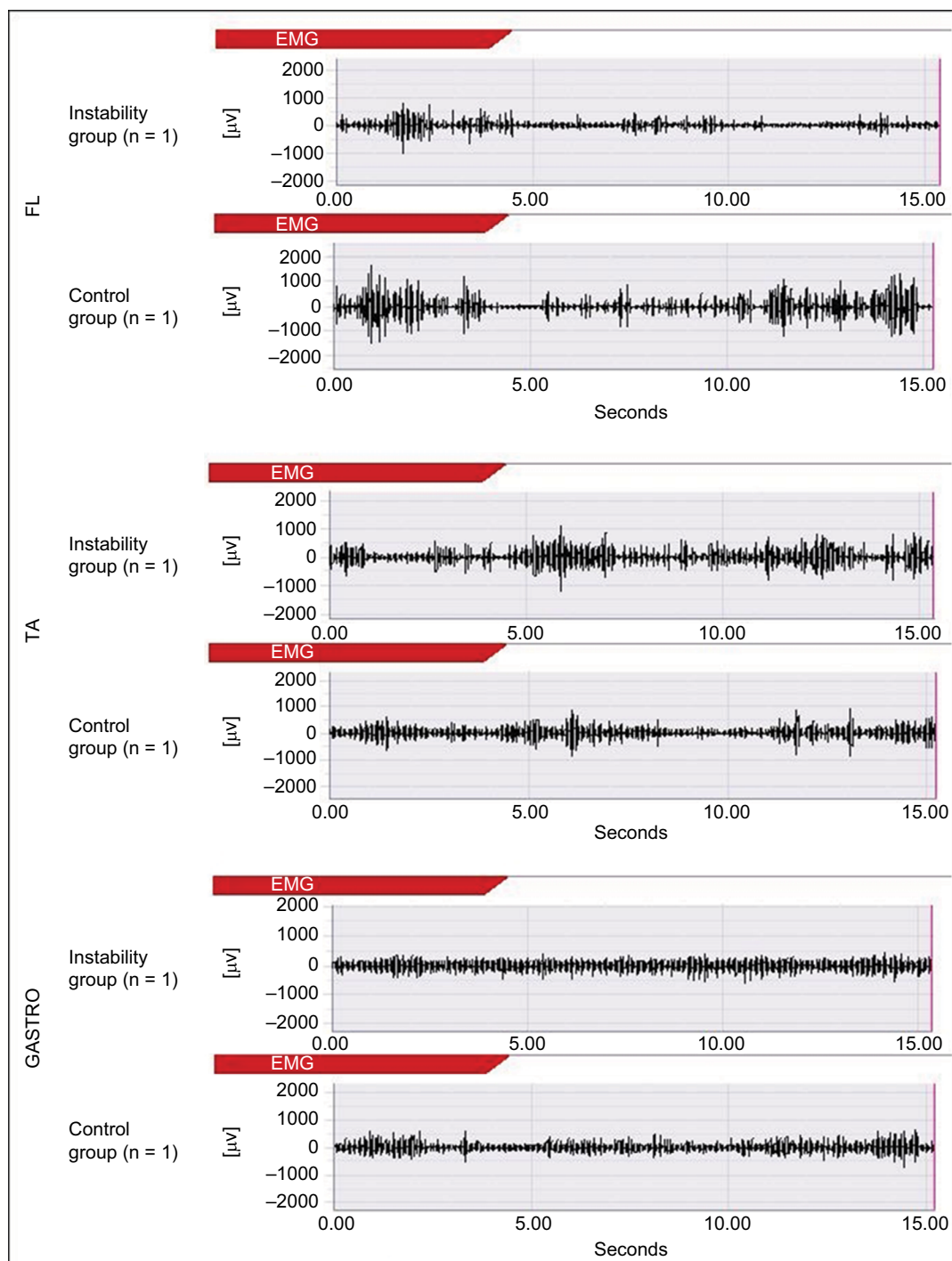
Figure 5 An example of the raw wave of muscle activities (n = 1).
Abbreviations: GASTRO, gastrocnemius; TA, tibialis anterior; FL, fibularis longus; EMG, electromyography.

interaction of the FL and TA is important to control MPP. Pozzi et al[40] have suggested that the increasing TA activity is important to increase ankle inversion torque (i.e., increasing LPP) during the SLB-C task. In addition, Feger and Hertel[41] showed that increasing FL activity leads to loading more toward the inside of the foot. In other words, it implies that the FL eversion function and TA inversion function lead to

increasing MPP and LPP, respectively. This result indicates that increasing FL function relative to the TA may induce MPP dominance. In a previous study, since TA activity leads the ankle to a close-packed dorsiflexed position, it was found that increasing TA activity before landing is important for ankle stability after landing.[39] However, our study results suggest that to increase TA activity in the state of remaining
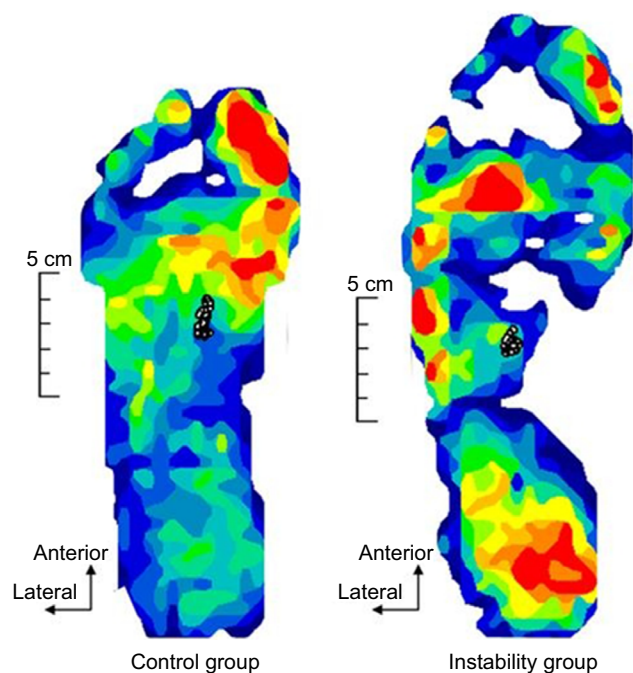
Figure 6 An example of the raw data of the COP displacement (n = 1).
Abbreviation: COP, center of pressure.

decreased FL activity may cause increasing plantar pressure in the lateral direction.

In general, strength and postural stability are important for an LAS rehabilitation program. Our research suggests increasing LPP/MPP if FL activity is not fully activated, even if ankle strength and postural stability have been fully recovered. Therefore, according to our research, we need to introduce not only the typical concentric ankle training and balance training used for LAS rehabilitation but also FL activation training, which can prevent the increasing LPP that occurs during some movements.

Limitations

Henry et al[28] showed that thigh- and trunk-muscle activities are important for postural control. Thus, one limitation of this study was a lack of information about thigh- and trunk-muscle activities. However, it has been reported that most of the postural control during SLB-C is achieved by the ankle joint;[42] therefore, this limitation likely had little influence on the results. Second, in this study, the selection of subjects and target leg was conducted by a single athletic trainer, which could imply a conflict with the double-blind study design. However, since it was analyzed by the consolidated possible anonymous, the author was not able to know the subjects' attributes (IG or CG) during analysis. Therefore, the bias of measurement and analysis is considered to be small. In addition, in regard to the plantar

pressure distribution area definition that can be biased, we defined the plantar pressure area using an objective landmark (Figure 3), and the ICC of plantar pressure analysis was high (Table 2). So we think the influence of bias on the results was small. Last, since only 11 athletes met the IG inclusion criteria, we did not perform prior power analysis. Also, the 95% CIs of the effect size crossed zero. However, when we performed a post hoc analysis, all results met medium power (LPP/MPP ratio: $1 - \beta = 0.61$, MPP: $1 - \beta = 0.70$, FL activity: $1 - \beta = 0.58$, TA/FL ratio: $1 - \beta = 0.89$). In addition, regarding the 95% CIs of the effect size crossing zero, we thought that it was caused by large individual differences in plantar pressure distribution and the values of muscle activity. However, since the values of plantar pressure distribution and muscle activity were almost the same in previous studies[14,21,43] and the ICCs of the measuring methods were high (Table 2), our results are reliable. Thus, these results likely show accurately the characteristics of plantar pressure distribution of the patients of recurrent sprain and its factors.

Disclosure

The authors report no conflicts of interest in this work.

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